Counteracting Gas Ingestion in a Hydrodynamic Bearing Spindle Motor

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Related Applications

This application claims priority of United States provisional application Serial Number 60/446,806, filed 02/12/03.

Field of the Invention

This application relates generally to data storage devices and more particularly to counteracting gas ingestion in a hydrodynamic bearing of a spindle motor.

Background of the Invention

Various types of data storage devices store digital data in magnetic or optical form on a rotating storage medium. Modern magnetic disc drives, for example, comprise one or more rigid discs that are coated with a magnetizable medium and mounted on the hub of a spindle motor for rotation at a constant high speed. Information is stored on the discs in a plurality of concentric circular tracks typically by an array of transducers ("heads") mounted to a rotary actuator for movement of the heads substantially radially relative to the discs. Each of the concentric tracks is generally divided into a plurality of separately addressable data sectors. The read/write transducer, e.g. a magneto-resistive read/inductive write head, is used to transfer data between a desired track and an external environment. During a write operation, data is written onto the disc track and during a read operation the magneto-resistive read element of the head senses the data previously written on the disc track and transfers the information to the external environment.

The spindle motor typically includes a stator, a rotor and a spindle or shaft. The rotor may alternatively rotate with the shaft or the shaft may be stationary so that the rotor rotates about the shaft. Within a data storage device, the rotor includes a hub for supporting one or more of the data storage discs. During idle periods when the data storage device is neither reading nor writing data to the disc, the stator continuously energizes the rotor to overcome wind resistance as well as friction in the bearings as the rotor spins at high speed. Typical spindle motor speeds include 4,200 revolutions per minute and beyond.

The rotor of the spindle motor may be supported by a hydrodynamic fluid bearing. These bearings have proven useful in reducing wear in the spindle, reducing power consumption of the spindle motor and reducing vibration from the spindle motor compared to ball bearings. However, hydrodynamic bearings are susceptible to failure due to loss of hydrodynamic stiffness resulting from gas being trapped in the fluid of the bearing.

During operation, the spindle motor naturally draws in or ingests gas from the surrounding environment in the data storage device. Some of this gas is forced into the fluid of the hydrodynamic bearing. When the spindle motor is operated for an extended period of time, in some cases many days, the gas forced into the fluid of the hydrodynamic bearing can accumulate to the point at which it displaces the fluid in certain areas of the bearing resulting in a loss of hydrodynamic stiffness and part contact wear. This can cause the motor bearing components to wear and eventually fail. Accordingly there is a need for a method and apparatus for counteracting gas ingestion in a hydrodynamic bearing spindle motor. The present invention provides a solution to this and other problems, and offers other advantages over the prior art.

Summary of the Invention

Against this backdrop the present invention has been developed. According to one embodiment of the present invention, a method of counteracting gas ingestion in a hydrodynamic bearing of a spindle motor in a data storage device comprises waiting for activity of a host connected with the data storage device to become idle. When the activity of the host becomes idle, a determination is made whether to release gas from a fluid of the hydrodynamic bearing of the spindle motor. Responsive to determining to release gas from the fluid of the hydrodynamic bearing of the spindle motor a motor spin down routine for the spindle motor is performed.

According to another embodiment of the present invention, a data storage device comprises a spindle motor having a rotating shaft, the rotating shaft supported by a hydrodynamic fluid bearing, a microprocessor coupled with the spindle motor to control rotation of the spindle motor, and a memory. The memory has stored therein a series of instructions representing a routine to counteract gas ingestion in a hydrodynamic bearing of the spindle motor in the data storage device. The routine, when executed by the microprocessor, causes the microprocessor to wait for activity of the host to which the data storage device is connected to become idle, determines whether to release gas from a fluid of the hydrodynamic bearing of the spindle motor, and responsive to determining to release gas from a fluid of the hydrodynamic bearing of the spindle motor, performs a motor spin down routine for the spindle motor.

These and various other features as well as advantages which characterize the present invention will be apparent from a reading of the following detailed description and a review of the associated drawings.

Brief Description of the Drawings

FIG. **1** is a plan view of a disc drive in accordance with an embodiment of the present invention illustrating the primary internal components of the disc drive.

FIG. **2** is a control block diagram for the disc drive shown in FIG. **1** illustrating the primary functional components.

FIG. **3** is a cross sectional side view of a spindle motor in the drive shown in FIG. **1** including a hydrodynamic bearing.

FIG. **4** is a flowchart illustrating, at a high level, a routine for counteracting gas ingestion in a hydrodynamic bearing spindle motor according to one embodiment of the present invention.

FIG. **5** is a flowchart illustrating an idle routine according to another embodiment of the present invention.

FIG. **6** is a flowchart illustrating a subroutine for determining whether to release gas from a hydrodynamic bearing according to another embodiment of the present invention.

FIG. **7** is a flowchart illustrating a motor spin down subroutine according to a further embodiment of the present invention.

Detailed Description

Embodiments of the present invention will be discussed with reference to a magnetic disc drive. One skilled in the art will recognize that the present invention may also be applied to any data storage device, such as an optical disc drive, a magneto-optical disc drive, or a compact disc drive, that utilizes a spindle motor having a hydrodynamic bearing.

FIG. **1** is a plan view illustrating the primary internal components of a disc drive incorporating one of the various embodiments of the present invention. The disc drive **100** includes a base **102** to which various components of the disc drive **100** are mounted. A top cover

104, shown partially cut away, cooperates with the base **102** to form an internal, sealed environment for the disc drive in a conventional manner. The components include a spindle motor **300** which rotates one or more discs **108** at a constant high speed. Information is written to and read from tracks on the discs **108** through the use of an actuator assembly **110**, which rotates during a seek operation about a bearing shaft assembly **112** positioned adjacent the discs **108**. The actuator assembly **110** includes a plurality of actuator arms **114** which extend towards the discs **108**, with one or more flexures **116** extending from each of the actuator arms **114**. Mounted at the distal end of each of the flexures **116** is a head **118** which includes a fluid bearing slider enabling the head **118** to fly in close proximity above the corresponding surface of the associated disc **108**.

During a seek operation, the track position of the heads **118** is controlled through the use of a voice coil motor (VCM) **124**, which typically includes a coil **126** attached to the actuator assembly **110**, as well as one or more permanent magnets **128** which establish a magnetic field in which the coil **126** is immersed. The controlled application of current to the coil **126** causes magnetic interaction between the permanent magnets **128** and the coil **126** so that the coil **126** moves in accordance with the well known Lorentz relationship. As the coil **126** moves, the actuator assembly **110** pivots about the bearing shaft assembly **112**, and the heads **118** are caused to move across the surfaces of the discs **108**.

The spindle motor **300** may be de-energized when the disc drive **100** is not in use for extended periods of time. The heads **118** are moved over park zones **120** near the inner diameter of the discs **108** when the drive motor is de-energized. The heads **118** are secured over the park zones **120** through the use of an actuator latch arrangement, which prevents inadvertent rotation of the actuator assembly **110** when the heads are parked.

A flex assembly **130** provides the requisite electrical connection paths for the actuator assembly **110** while allowing pivotal movement of the actuator assembly **110** during operation. The flex assembly includes a printed circuit board **132** to which head wires (not shown) are connected; the head wires being routed along the actuator arms **114** and the flexures **116** to the heads **118**. The printed circuit board **132** typically includes circuitry for controlling the write currents applied to the heads **118** during a write operation and a preamplifier for amplifying read signals generated by the heads **118** during a read operation. The flex assembly terminates at a flex bracket **134** for communication through the base deck **102** to a disc drive printed circuit board (not shown) mounted to the bottom side of the disc drive **100**.

FIG. **2** is a control block diagram for a disc drive illustrating the primary functional components of a disc drive incorporating one of the various embodiments of the present invention and generally showing the main functional circuits which are resident on the disc drive printed circuit board and used to control the operation of the disc drive **100**. The disc drive **100** is operably connected to a host computer **140** in a conventional manner. Control communication paths are provided between the host computer **140** and a disc drive microprocessor **142**, the microprocessor **142** generally providing top level communication and control for the disc drive **100** in conjunction with programming for the microprocessor **142** stored in microprocessor memory (MEM) **143**. The MEM **143** can include random access memory (RAM), read only memory (ROM) and other sources of resident memory for the microprocessor **142**.

The discs **108** are rotated at a constant high speed by a spindle motor control circuit **148**, which typically electrically commutates the spindle motor **300** (FIG. **1**) through the use, typically, of back electromotive force (BEMF) sensing. During a seek operation, wherein the actuator **110** moves the heads **118** between tracks, the position of the heads **118** is controlled through the application of current to the coil **126** of the voice coil motor **124**. A servo control circuit **150**

provides such control. During a seek operation the microprocessor **142** receives information regarding the velocity of the head **118**, and uses that information in conjunction with a velocity profile stored in memory **143** to communicate with the servo control circuit **150,** which will apply a controlled amount of current to the voice coil motor coil **126**, thereby causing the actuator assembly **110** to be pivoted.

Data is transferred between the host computer **140** or other device and the disc drive **100** by way of an interface **144**, which typically includes a buffer to facilitate high speed data transfer between the host computer **140** or other device and the disc drive **100**. Data to be written to the disc drive **100** is thus passed from the host computer **140** to the interface **144** and then to a read/write channel **146**, which encodes and serializes the data and provides the requisite write current signals to the heads **118**. To retrieve data that has been previously stored in the data storage device **100**, read signals are generated by the heads **118** and provided to the read/write channel **146**, which performs decoding and error detection and correction operations and outputs the retrieved data to the interface **144** for subsequent transfer to the host computer **140** or other device.

FIG. **3** is a cross sectional side view of the spindle motor **300** including a hydrodynamic bearing. This example illustrates the spindle motor **300** secured to the base plate **102** of the data storage device **100**. The spindle motor **300** is illustrated separately from the discs **108** and the top cover **104** for purposes of clarity. The spindle motor **300** in this example includes a rotating shaft **302** supported for rotation by a hydrodynamic bearing **304**. Alternatively, the shaft **302** may be stationary and a rotating sleeve (not shown) around the shaft may be supported for rotation by a hydrodynamic bearing **304**.

The hydrodynamic bearing **304** includes a sleeve **306** that forms a recess for receiving a thrust plate **308** at one end of the shaft **302**. A counter plate **310** cooperates with surfaces of the

thrust plate **308** to form a hydrodynamic thrust bearing which supports the shaft **302** for rotation. A hydrodynamic journal bearing is established in a gap (not shown) between the sleeve **306** and the rotating shaft **302** as well as the thrust plate **308** supported on the shaft **302**. Specifically, the shaft **302** and the thrust plate **308** are supported for rotation by fluid inserted into the gap between the surfaces of the shaft and thrust plate, and the corresponding inner surface of the sleeve **306** and the counter plate **310**. A pattern of grooves formed on these surfaces helps to establish appropriate pressures in the fluid used to form the hydrodynamic bearing **304**, all in accordance with known technology in the field of hydrodynamic bearings.

A cylindrical shaped hub **320** extends radially outward from an upper end **321** of the shaft **302** and includes a bottom radial flange **322** and a cylindrical surface **324** extending upward from the flange **322** to support one or more discs **108**. Once one or more discs **108** are loaded on the hub **320**, a clamp ring is attached to a top surface **326** of the hub **320** to secure the discs **108** to the hub **320**. A set of permanent magnets **330** are secured to an inner surface of the hub **320** to complete the rotor for the spindle motor **300**.

The base plate **102** of the data storage device defines a recessed portion **340** for receiving the spindle motor **300**. A cylindrical motor mount **350** is centered within the recessed portion **340** and defines an axial opening for receiving the sleeve **306** and counter plate **310** of the hydrodynamic bearing **304**. The cylindrical motor mount **350** extends vertically upward and terminates at an upper end **352** that defines an annular ring. An inner cylindrical surface **356** of the cylindrical motor mount **350** supports an outer cylindrical **357** surface of the sleeve **306** while an outer cylindrical surface **358** of the motor mount **350** engages an inner cylindrical surface **359** of a stator **360**.

The stator **360** is formed from a stack of stator laminations **362** and associated stator windings **364**. While the stator **360** is preferably press fit around the outer cylindrical surface **358**

of the motor mount **350**, a bottom stator lamination **368** may be supported by a shoulder **354** formed in the outer cylindrical surface **358** of the motor mount **350**. Additionally, the inner cylindrical surface **359** of the stator laminations **362** may be secured to the outer cylindrical surface **358** of the motor mount **350** by an adhesive.

FIG. **4** is a flowchart illustrating, at a high level, a routine **400** for counteracting gas ingestion in a hydrodynamic bearing spindle motor according to one embodiment of the present invention. This routine **400** may be implemented in a series of instructions stored in the memory **143** of the disc drive **100** or other data storage device and executed by the microprocessor **142**.

The routine **400** begins with a query operation **405** to determine whether there is activity from the host to which the data storage device may be connected. That is, a check is made as to whether any new commands have been received at the data storage device from the host. If a command has been received from the host, control passes to command handling operation **410** where the command will be handled. After handling the command in operation **410**, control returns to query operation **405**. Together, the loop between query operation **405** and command handling operation **410** may be considered to comprise waiting for activity of a host to which the data storage device is connected to become idle.

Once a determination is made at query operation **405** that the host has become idle, control passes to query operation **415**. At query operation **415**, a determination is made as to whether to release gas from the hydrodynamic bearing of the spindle motor. According to one embodiment of the present invention, as will be discussed below with reference to FIG. **6**, this determination **415** may be based on comparing the amount of time since a previous spin down routine and a predetermined amount of time. Alternatively, this determination **415** may be based on other considerations. For example, the determination **415** may be based on a specified time of day having been passed.

If, at query operation **415**, a determination to release gas from the hydrodynamic bearing of the spindle motor is made, control passes to a motor spin down routine **420**. Details of one possible spin down routine will be discussed below with reference to FIG. **7**. Regardless of the exact spin down routine to be used, spinning down or stopping the motor for a brief period of time allows the pressure within the hydrodynamic bearing to equalize which in turn allows gas trapped in the fluid to escape. Therefore, periodically performing a spin down routine reduces the number of failures due to gas ingestion into the fluid of the hydrodynamic bearing.

For clarity, FIG. **4** illustrates a routine for counteracting gas ingestion in a hydrodynamic bearing spindle motor as a stand-alone routine. However, this routine may be performed along with other routines that are normally handled during idle time of the data storage device. For example, there may be a number of utility routines that perform various housekeeping functions within the data storage device whenever the data storage device is idle. Therefore, the routine for counteracting gas ingestion in a hydrodynamic bearing spindle motor may be integrated with these other utilities in an idle time routine performed by the data storage device when it is not handling commands from a host.

FIG. **5** is a flowchart illustrating an idle time routine according to another embodiment of the present invention. This routine **500** may be implemented in a series of instructions stored in the memory **143** of the disc drive **100** or other data storage device and executed by the microprocessor **142**.

The routine **500** begins with a query operation **505** in which a determination is made as to whether the data storage device is in a power management mode. Many data storage devices utilize a power management mode that, in an effort to save wear on the mechanical components of the data storage device, shuts down the data storage device when it has not been in use for some time. If, at query operation **505**, a determination is made that the data storage device is in a

power management mode, control passes to power management processing operation **515** where power management mode continues until a new host command is received.

If the data storage device is not in power management mode at query operation **505**, control passes to determination operation **510** where a determination is made as to whether to release gas from the hydrodynamic bearing of the spindle motor **300**. That is, idle time routine **500** may, for example, call a subroutine or otherwise initiate another routine that will make the determination as to whether to release gas from the hydrodynamic bearing of the spindle motor **300**. According to one embodiment of the present invention, as will be discussed below with reference to FIG. **6**, this determination may be based on comparing the amount of time since a previous spin down routine and a predetermined amount of time. Alternatively, this determination may be based on other considerations. For example, the determination may be based on a specified time of day having been passed.

Control then passes to query operation **520** where a determination is made as to whether a new command has been received from the host. If a new command has been received, the idle routine ends and the new command is handled by the data storage device.

If no new command has been received at query operation **520**, control passes to query operation **525** where a determination is made as to whether utility routines are to be performed. That is, utility routines that perform various housekeeping functions on the data storage device may be executed only periodically. Therefore, there may not be a current need for the utility routines to execute.

If utility processing is to be performed, control passes to determination operation **530** where another determination as to whether to release gas from the hydrodynamic bearing is made. As indicated above, this determination may be based on comparing the amount of time since a previous spin down routine and a predetermined amount of time as will be discussed below with

reference to FIG. **6**. Alternatively, this determination may be based on other considerations. For example, the determination may be based on a specified time of day having been passed.

Control then passes to utility operation **535** where other utility routines are performed. Such housekeeping utilities may include, for example, a utility that reads data off the media and re-writes or refreshes any data that is becoming difficult to read. After the utility routines are executed at utility operation **535**, control passes to query operation **540**.

At query operation **540** a determination may be made as to whether more utilities should be performed. If more utilities should be performed, control returns to determination operation **530**. If no more utilities are to be performed, control returns to query operation **520** for a determination of whether a new host command has been received.

Regardless of other routines that might be done by the data storage device when it is not receiving commands from the host, the basic routine for counteracting gas ingestion in a hydrodynamic bearing spindle motor comprises waiting for activity of a host to which the data storage device is connected to become idle, determining whether to release gas from the hydrodynamic bearing of the spindle motor, and responsive to determining release gas from the hydrodynamic bearing performing a motor spin down routine for the hydrodynamic bearing spindle motor.

FIG. **6** is a flowchart illustrating a routine for determining whether to release gas from a hydrodynamic bearing according to another embodiment of the present invention. This routine **600** may be implemented in a series of instructions stored in the memory **143** of the disc drive **100** or other data storage device and executed by the microprocessor **142**.

The routine **600** begins with determination operation **605** where an amount of time since the previous spin down is determined. This time may be based on a simple counter, a time of day clock, or another means. For example, the time since the last spin down may be determined by

the difference between a timer value stored when the last spin down was completed and the current value of that timer.

Control then passes to optional query operation **610** where a determination may be made as to whether the spin down routine has been disabled. That is, the spin down routine may be disabled by a software switch stored in memory or by another means. If, at query operation **610**, a determination is made that the spin down routine has not been disabled, control passes to query operation **615**.

At query operation **615**, a comparison is made between the amount of time since the previous spin down and a predetermined amount of time between spin downs. For example, if the time since the previous spin down determined in determination operation **605** is found to be greater than or equal to a predetermined interval between spin downs, a spin down routine may be initiated at processing block **620**. That is, determination routine **600** may call a subroutine that or otherwise initiate another routine that will perform a spindle motor spin down. Details of one possible spin down routine will be discussed below with reference to FIG. **7**.

The exact value for the predetermined amount of time between spin downs may vary significantly depending upon the use of the data storage device. Considerations affecting the value used include usage of the data storage device and availability requirements balanced against prevention of failures due to wear caused by gas trapped in the fluid of the hydrodynamic bearing. According to one embodiment of the present invention, the predetermined amount of time may be less than or equal to 24 hours. According to another embodiment of the present invention, the predetermined amount of time may be 12 hours.

FIG. **7** is a flowchart illustrating a motor spin down routine according to a further embodiment of the present invention. This routine **700** may be implemented in a series of

instructions stored in the memory **143** of the disc drive **100** or other data storage device and executed by the microprocessor **142**.

The routine begins with store operation **705** where information regarding the original state of the data storage device is saved. For example, data that might be saved includes but is not limited to reset state information, data caches, interrupt states, etc. Control then passes to query operation **710**.

At query operation **710** a determination is made regarding whether a new command or a reset request has been received. If a new command or a reset request has been received, control will pass to restore operation **740** where the original state information will be restored and the spin down routine will be aborted so that the command or request may be handled immediately.

If no new command or reset request is detected at query operation **710**, control passes to spin down operation **715** where the motor will be spun down. This may involve simply turning off the motor. Optionally, there may be a slight delay before proceeding in order to allow the motor time to decelerate and stop. Of course, if used, this time delay may vary significantly depending on the motor, the size and number of discs in the data storage device, etc.

Control then passes to wait operation **720** where processing will pause for a short, predetermined interval. This pause allows the pressure within the hydrodynamic bearing to equalize which in turn allows gas trapped in the fluid to escape. This time may vary depending upon the motor used in the data storage device. However, the time will generally be brief and measured in seconds. For example, 2 to 5 seconds may be an adequate amount of time to allow gas to escape from the fluid in some hydrodynamic bearings. Of course, longer times may also be used ranging from 5 seconds to several minutes. After this time has passed, control passes to spin up operation **725**.

At spin up operation **725** the motor is spun up or restarted. This may involve simply turning on the motor. Optionally, there may be a slight delay before proceeding in order to allow the motor time to accelerate to a normal operating speed. Of course, if used, this time delay may vary significantly depending on the motor, the size and number of discs in the data storage device, etc.

Control then passes to query operation **730**. At query operation **730** another check may be made as to whether a new command or reset request has been received while the motor was stopped. If a new command or a reset request has been received, control passes to restore operation **740** where the original state information will be restored and the spin down routine will be aborted so that the command or request may be handled immediately. If no new command or reset request has been received, control passes to reset operation **735.**

At reset operation **735** a timer indicating when the last spin down had been completed is reset. As discussed above, this timer may be used to determine when the spin down routine **700** will next be executed.

Control then passes to restore operation **740**. At restore operation **740** the original state information for the data storage device stored during store operation **705** will be restored.

Described in another way, a method (such as **400**) of counteracting gas ingestion in a hydrodynamic bearing (such as **304**) of a spindle motor (such as **300**) in a data storage device (such as **100**), according to one embodiment of the present invention, comprises waiting for activity of a host connected with the data storage device (such as **100**) to become idle. When the activity of the host becomes idle, a determination (such as **415** or **600**) is made whether to release gas from a fluid of the hydrodynamic bearing (such as **304**) of the spindle motor (such as **300**). Responsive to determining to release gas from a fluid of the hydrodynamic bearing (such as **304**)

of the spindle motor (such as **300**) a motor spin down routine (such as **420** or **700**) for the spindle motor (such as **300**) is performed.

According to another embodiment of the present invention, a data storage device (such as **100**) comprises a spindle motor (such as **300**) having a rotating shaft (such as **302**), the rotating shaft (such as **302**) supported by a hydrodynamic bearing (such as **304**), a microprocessor (such as **142**) coupled with the spindle motor (such as **300**) to control rotation of the spindle motor (such as **300**), and a memory (such as **143**). The memory (such as **143**) has stored thereon a series of instructions representing a routine (such as **400** or **500**) to counteract gas ingestion in a hydrodynamic bearing (such as **304**) of the spindle motor (such as **300**) in the data storage device (such as **100**). The routine, when executed by the microprocessor (such as **142**), causes the microprocessor (such as **142**) to wait for activity of a host to which the data storage device (such as **100**) is connected to become idle, determine whether to release gas from a fluid of the hydrodynamic bearing (such as **304**) of the spindle motor (such as **300**), and responsive to determining to release gas from a fluid of the hydrodynamic bearing (such as **304**) of the spindle motor (such as **300**), perform a motor spin down routine for the spindle motor (such as **300**).

It will be clear that the present invention is well adapted to attain the ends and advantages mentioned as well as those inherent therein. While a presently preferred embodiment has been described for purposes of this disclosure, various changes and modifications may be made which are well within the scope of the present invention. For example, the determination of whether to release gas from the hydrodynamic bearing may be based on criteria other than time or may use varying amounts of time between spin down routines. Additionally, the amount of time that the spindle motor is stopped during a spin down routine may vary. Further, one skilled in the art will recognize that the present invention may also be applied to any data storage device, such as an optical disc drive, a magneto-optical disc drive, or a compact disc drive, that utilizes a spindle

motor having a hydrodynamic bearing. Numerous other changes may be made which will readily suggest themselves to those skilled in the art and which are encompassed in the spirit of the invention disclosed and as defined in the appended claims.